LASERTRACER – A NEW TYPE OF SELF TRACKING LASER INTERFEROMETER

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1. INTRODUCTION

The LaserTracer, developed by PTB (German's National Metrology Institute) and NPL (UK's National Physical Laboratory), is a new self tracking interferometer which delivers highest precision distance measurements to a moving reflector. Compared to a Laser Tracker the new LaserTracer's accuracy is independent from all mechanical imperfections of the device. This patented technology and first applications for CMM or machine tool calibration will be described.

2. BASIC PRINCIPLE OF THE TRACKING INTERFEROMETER (TI)

The distance measurement uncertainty of the TI is the dominant uncertainty contributor of the system. Especially the stability of the point of rotation is of great importance. As commercial tracking interferometers do not offer distance measurement uncertainties in the submicron range a new high precision tracking interferometer has been designed. In this design, the interferometer moves in a gimbal mount around a fixed sphere serving only as a reference mirror for the interferometer. Due to this principle, radial and lateral deviations of the mechanical axes of rotation do not significantly affect the measurement accuracy. The design is fundamentally different from commercial laser trackers in which the light beam is deflected by moving mirrors or prisms. In contrast to other similar systems currently under development , the reference sphere does not have any mechanical function, therefore no external forces can alter its position.

The accuracy of the TI length measurement depends significantly on the quality of the reference sphere surface and its unchanged position in space. To minimize its influences, the reference sphere has a form error below 30nm. It is mounted on an invar stem to avoid any displacements due to thermal expansion. Atmospheric conditions such as temperature, barometric pressure and relative humidity are monitored to numerically correct the laser signal.

The interferometer uses an external He-Ne laser. The light is transmitted to the interferometer by a glass fibre. This reduces the weight of the laser interferometer and eliminates thermal influences. The reference beam passes directly to the opto-electronic detection unit, while the measuring beam is reflected to the reference sphere and the external reflector before it is superimposed on the reference beam.

A part of the reference beam is redirected onto a four-quadrant diode. The four quadrant diode detects misalignment between interferometer and external reflector. Its signal is used to track the external reflector.

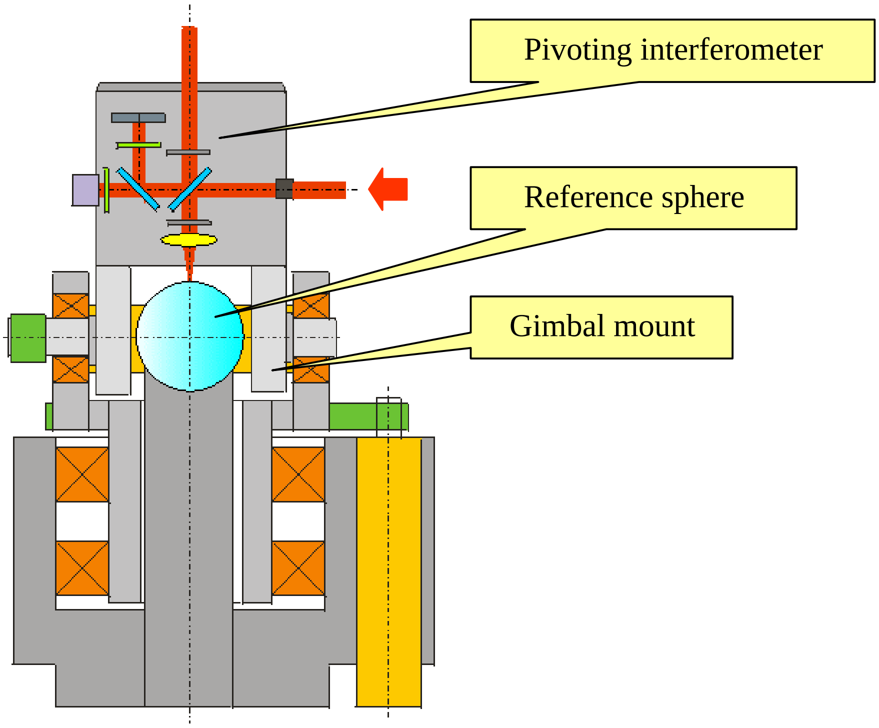

Fig. 1 : Tracking laser interferometer

The total dimensions of the TI are 200mm in diameter and 250mm in height. Its weight is 7 kg so it can be placed easily in any coordinate measurement machine or tooling machine.

Fig. 2 : The LaserTracer with housing

3. CMM CALIBRATION WITH TRACKING INTERFEROMETER USING SEQUENTIAL MULTILATERATION

The determination of systematic errors for CMMs and machine tools has a long scientific history. Many different approaches have been presented and some have been successfully implemented. Examples are direct analysis by means of interferometers, straight edges, squareness standards [2], analysis by measurement of ball- or hole plates [5] or the use of interferometric length measurements along fixed lines [4].

Recently, a method was developed by PTB that uses commercial laser trackers to generate “virtual” planar reference patterns from interferometric length measurements [7]. The method yielded high accuracy but the relatively long measurement time and complicated data handling procedures were identified as major drawbacks. Based on the experience of this method, a new approach has now been developed jointly by PTB and NPL, which uses a spatial grid of positions to directly derive the systematic parameters from interferometric length measurements. The principle of this method is described in the following.

3.1. Principle

The concept is based on the measurement of relative distance change between reference points that are fixed to the base and points fixed to the machine head. These measurements are realised by a tracking interferometer, which is mounted on the work piece table and a retro reflector that is attached to the machine head. Fig. 3 shows a typical set up.

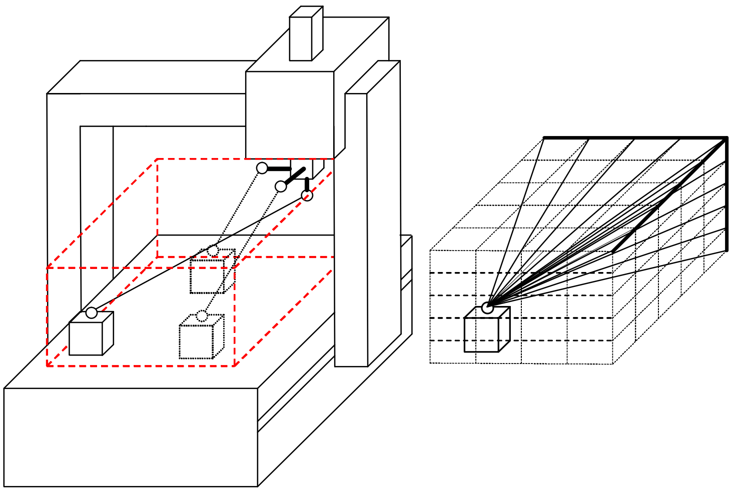

Fig. 3: A laser tracer in three positions on the workpiece table. For each position, the retro reflector has a different offset from the reference point of the machine head.

For each combination, the machine is moved through a set of positions in a spatial grid. At each grid position, the machine stops and the associated measured distance is recorded by the tracking interferometer. The nominal distance change (under the assumption of a perfect machine) can be directly calculated from the position of the reference point and the positions of all three axes. Errors of the machine show up in differences between the measured and the nominal distance changes. If systematic error behaviour of the machine is assumed, these differences can be used to evaluate the parametric errors by a "best-fit" calculation based on the kinematical model. Preconditions for this are a sufficient number of measurements and a linearised system of equations that are well conditioned.

3.2. Uncertainty analyses

One of the advantages of the proposed method is the simple structure of the input data. It consists of n lines, each one containing the three coordinates indicated by the CKS, the measured length and an identifier of the tracker position to which the distance measurement is related. Due to the nature of the method, each single sampling point of the parametric errors has an individual uncertainty that depends in a complex manner upon the number of distance measurements, their uncertainties and the geometrical conditions. Therefore Monte-Carlo-Techniques (MCT) for uncertainty evaluation have been employed. Normally distributed random numbers can be generated and added to the simulated distance measurement. This alters the resulting set of parameters calculated by the mathematical module. If the complete evaluation is repeated a sufficient number of times with new random numbers, a standard deviation for each error parameter sampling point can be understood as its standard uncertainty. This approach cannot only be the base to achieve traceable results for a calibration for systematic parameters, but can also help to optimise the measurement set up.

3.3. Verification on a high accuracy CMM

After testing the algorithms by means of simulation software, the concept has been verified by comparison with an established, well-known method for error mapping. This reference method, developed by PTB, is based on the measurement of calibrated 2-D artefacts (ball or hole plates). The reference artefact was a hole plate made of Zerodur®. For the first tests a prototype tracking interferometer developed at NPL [1] has been used in combination with a commercial Cat's eye reflector. Both error mapping procedures have been performed with numerical correction deactivated; therefore the errors correspond to the physical shape of the guideways and do not represent the final accuracy of the machine. After mapping the CMM with both methods the calculated parametric errors have been compared directly showing compliance of all parameters, mostly in the sub-micron range. As an example Fig. 4 shows the 6 parametric error functions of the Y-axis (motion along the portal) assessed by multilateration and by the PTB hole plate method [5].

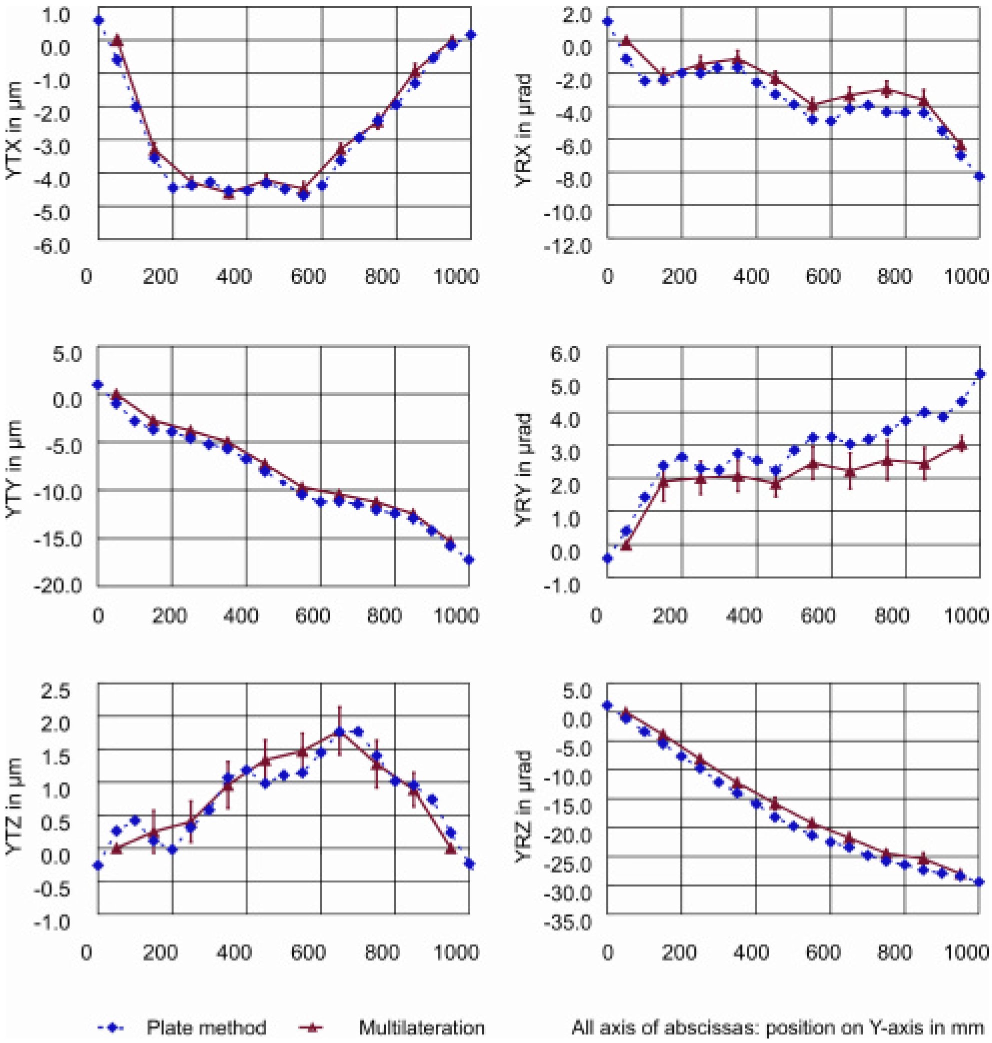

Fig. 2: Parametric errors of the Y-axis with inactive numerical correction

4. OUTLOOK

The tracking interferometer currently exists in a prototype status with two different designs at NPL and PTB. The design described in this paper is the PTB version of the basic principle and is now transferred into a product with minor redesign as a contribution for serial production. The TI will be commercially available in second half of 2005.

5. ACKNOWLEDGEMENT

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